DESCRIPTIONS OF LARVAE AND BIOLOGY OF
CYRTOBAGOUS (COLEOPTERA: CURCULIONIDAE):
AGENTS FOR BIOLOGICAL CONTROL OF SALVINIA

B. M. May and D. P. A. Sands

(BMM) Entomology Division, DSIR, Private Bag Auckland, New Zealand;
(DPAS) Division of Entomology, CSIRO, Private Bag 3, Indooroopilly, Queensland 4068, Australia.

Abstract. — The larvae of *Cyrtobagous singularis* Hustache and *C. salviniae* Calder and Sands are described and figured. A key to the larvae of these and to the larvae of three other erirhinine weevils, *Neochetina bruchi* Hustache, *N. eichhorniae* Warner and *Neohydronomus pulchellus* Hustache, used for biological control of water weeds, is included. Differences are reported between the biology of *C. singularis* in Zimbabwe, southern Africa and *C. salviniae* in Queensland, Australia, where the species were introduced for biological control of the aquatic weed, *Salvinia molesta* Mitchell. Their potential as biological control agents is discussed.

Some South American sub-aquatic weevils (Erirhininae) are useful agents for biological control of aquatic weeds. One species, *Neohydronomus pulchellus* Hustache, controlled water lettuce, *Pistia stratiotes* L. in Australia (Harley et al., 1984). The genera *Neochetina* and *Cyrtobagous* contain species which controlled respectively, water hyacinth, *Eichhornia crassipes* (Mart.) Solms (Wright, 1981) and the floating fern salvinia, *Salvinia molesta* Mitchell (Room et al., 1981) when introduced into Australia for that purpose. Both genera contain species that have different potential for control of the weeds (DeLoach and Cordo, 1976; Sands and Schotz, 1985).

Cyrtobagous singularis Hustache was one of three insects introduced from Trinidad to southern Africa for biological control of salvinia (Bennett, 1975). Despite establishment of this weevil in Botswana (Procter, 1984), salvinia continued to be a serious weed, particularly in the Chobe River and neighbouring Caprivi region (Edwards and Thomas, 1977). In Australia, a closely related weevil, *C. salviniae* Calder and Sands originally from Brazil, successfully controlled salvinia in northern Queensland and Northern Territory (Room et al., 1984). Laboratory studies by Sands and Schotz (1985) have since shown differences in the feeding behaviour of the two weevil species that provide an explanation why *C. salviniae* has succeeded as a biological control agent for salvinia where *C. singularis* had failed.

In this paper we describe the larvae of the two closely related *Cyrtobagous* spp. and provide a key (May) for distinguishing them from three other environmentally important erirhinine larvae that could be present in the same waters. We report differences in larval biology of the two *Cyrtobagous* spp. in the field and discuss their potential as biological control agents for salvinia (Sands).

Descriptions of Larvae

The system of nomenclature used in the descriptions is substantially that of Thomas (1957). The methods of dissection, preparation and examination of larvae are given in May (1971). Numbers of setae (referring to one side only) are shown with the modal numbers for Curculionidae in Table 1.

Abbreviations used in text and figures: Abd, abdominal segment; als, antero-lateral setae; ams, anteromedian setae; ant, antenna; at, airtubes; av, anterior ventriculus; cnp, cryptonephridium; des, dorsoepicranial setae; dlcs, dorsal lacinial setae; dpls, dorsopleural setae; fs, frontal setae; hb, hypopharyngeal bracon; les, lateral epicranial setae; lrms, labral setae; lsts, laterosternal setae; mes, median epipharyngeal setae; msts, mediosternal setae; Mpts, Malpighian tubules; oc, ocelli; pds, postdorsal setae; pls, pleural setae; plbs, postlabial setae; pms, premental sclerite; poc, postoccipital condyle; pp, pygopod; prn, pronotum; prs, prodorsal setae; prv, proventriculus; pv, posterior ventriculus; rs, retractile section; sp, spiracle; sps, spiracular setae; t, tormae; Th, thoracic segment; tr, trachea; ves, ventral epicranial setae; vlcs, ventral lacinial setae; vpls, ventropleural setae.

Subfamily Erirhininae

Head free, usually subspherical, emarginate behind; postoccipital condyles conspicuous, acutely triangular; 2 pairs of ocelli; frontal setae reduced in number, fs 4 constant. Antennae broadly conical or hemispherical. Mandibles usually bifid at apex, with or without supplementary teeth. Labral tormae subparallel or convergent. Labial palpi 1- or 2-segmented. Spiracles often reduced or strongly modified; dorsal on Abd VIII. Anus terminal or ventral, 4-lobed. Alimentary canal relatively simple, lacking mycetomes and gastric caeca; 6 Malpighian tubules; cryptonephridium weak.

Key to Larvae of some Erirhininae Used for Biological Control of Water Weeds

1. Abdomen with 1 pair of spiracles upstanding (Abd VII). Head bright red brown. On water hyacinth *Eichhornia crassipes* ....
   .... *Neochetina eichhorniae* Warner, *N. bruchi* Hustache
 – Abdomen with 6 pairs of spiracles upstanding on dorsum (Abd II–VII). Head not red brown 2
2. Head pale yellow, unpatterned. Spiracles of Abd II–VII upstanding laterally, well separated. Abd VIII/IX sharing a sclerotized, red-brown, dorsal plate; lacking elongate trailing hairs. Abd X lacking anal hooks. On water lettuce (*Pistia stratiotes*) .... *Neohydronomus pulchellus* Hustache
 – Head dusky brown and cream, variegated. Spiracles of Abd II-VII upstanding on dorsum, close together. Abd VIII/IX lacking a sclerotized dorsal plate; bearing elongate, trailing hairs. Abd X bearing anal hooks. On floating ferns (*Salvinia* spp.) .... *Cyrtobagous* 3
3. Head with median epicranial area pallid. Abd VIII with prodorsal seta red-brown, erect; both dorsopleural setae elongate, subequal in length (Fig. 1) .... *C. singularis* Hustache
 – Head with median epicranial area dusky brown. Abd VIII lacking a dark, erect seta; major dorsopleural seta 3× longer than the minor one (Fig. 2) .... *C. salviniae* Calder and Sands

Table 1. Setal index for *Cyrtobagous* larvae and modal numbers for Curculionidae.

|		Modal Numbers				Modal Numbers
Prothorax				Abdomen X		
Pronotal	9–10	v		Anal	2	v
Dorsopleural	1	v		Head		
Ventropleural	2	2				
Mediosternal	1	1		Dorsal	4	5
Pedal area	4	v		Posterior	4*	4*
				Lateral	2	2
Meso-, Metathorax				Ventral	2	2
Prodorsal	1	1		Frontal	2	5
Postdorsal	3	4		Clypeal	2*	2
Dorsolateral	2	v		Labral	3	3
Alar area	1 + 1*	v		Mandibular	2*	2
Dorsopleural	1	1		Epipharyngeal Lining		2
Ventropleural	1	1				
Mediosternal	1	1		Anterolateral	3	3
Pedal area	4	v		Anteromedian	1	2
				Median	3	2
Abdomen I–VIII						
Prodorsal I–VII	1	1		Maxilla		
VIII	1	v		Dorsal	7	v
Postdorsal	5	5		Lacinia		
VII	5	5		Ventral	4	v
VIII	4	v		Palpal	0	1*
Spiracular	?	2		Stipital	1	1
VII	?	1		Palpiferal	2	2
VIII	0	1		Labium		
Dorsopleural	2	2		Postlabial	3	3
Ventropleural	2	2		Prelabial	1	1
Laterosternal	1	1		Ligular	1	2
Mediosternal	2	2				
Abdomen IX						
Dorsal	3	v				
Pleural	2	2				
Sternal	2	2				

* minute setae; v, variable.

Genus *Cyrtobagous* Hustache

Cyrtobagous Hustache, 1929. Type species, *Cyrtobagous singularis* Hustache. Orig. desig.

Larva.—Body slender, gently curved and tapered to a pygopod; spiracles up-standing on dorsum. Setae variously modified as hooks and trailing hairs. Head free, subspherical, emarginate behind; endocarinal line absent; sutures distinct, ecdysial line dark, half length of coronal suture; *des* 3 placed within frons, *des* 4 absent; *fs* 4 and *fs* 5 subequal, *fs* 1, 2, 3, absent. Ocelli distinct, close together. Antennae mushroom-shaped on basal cone which bears 1 sensory papilla. Mandibles apically bifid with inner margin of incisor lobe crenate. Hypopharyngeal bracon clear. Labrum gently rounded or truncate; tormae slender, subparallel. Labial palpi 1-segmented; premental sclerite broken before middle. Maxilla with lacinia (mala) acute, almost as long as palpus. Spiracles of Abd II–VII external,
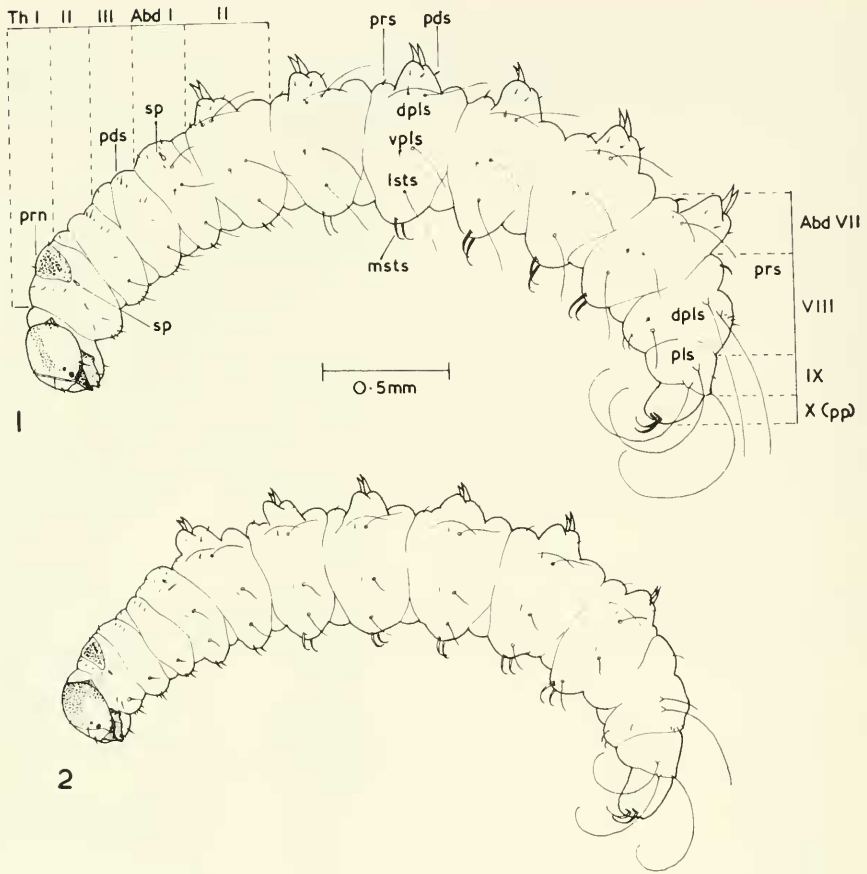
Figs. 1, 2. *Cyrtobagous* larvae, lateral view. 1, *C. singluaris.* 2, *C. salviniae.*

acute, set on a median ampulla, close together, erect, retractile; those of meso-thorax, Abd I and Abd VIII minute, vestigial. Abdominal II–VII *pds-sps* set around ampulla; *lsts* slender, elongate, outstanding horizontally (perhaps to func-tion as balancers in the water); some setae of Abd VII and IX trailing, much longer than *lsts*; *msts* of Abd III–VII relatively short, strong, curved backwards; basal socket extended caudad. Anal segment produced to form a tubular pygopod terminated by 4 strong, ventrally braced hooks, curved forwards. Alimentary canal with proventriculus simple, slender; anterior ventriculus elongate, rugose; pos-terior section 1-coiled. Malpighian tubules evenly distributed around ileocolic valve, 2 pairs looped cephalad against ventriculus, 1 pair intertwined caudad with hind gut. Cryptonephridium symmetrical. Rectal bracon not visible.

Note on spiracles.—The construction of the spiracles in *Cyrtobagous* is of a type similar to that of *Neochetina bruchi* and of the rice water weevil *Lissorhoptrus oryzophilus* Kuschel. The apical section is formed by the fused airtubes which are completely sclerotized and tapered to a fine point. It contains no internal structures other than a channel formed by the infolded walls. Below the airtubes, a retractile, concertina-like tube, of similar length, situated within the raised ampullae, leads into a branch of the trachea. The spiracle of *L. oryzophilus* as described by Isely

and Schwardt (1930) differs in detail. The basal part of the external "hook" is formed of heavy, infolded rings and there is no obvious retractile section. In addition, there is a minute blade-like process at the extreme tip, noted by May (1970) which is absent in *Cyrtobagous*.

Cyrtobagous singularis Hustache
Figs. 1, 3–13

Cyrtobagous singularis Hustache, 1929: 228.

Larva.—Maximum size 4.2 × 1.6 mm. Head width: 1st instar, 0.18 mm; 2nd instar, 0.24 mm; 3rd instar, 0.33 mm. Setal index as in Table 1. Pleural and most dorsal setae fine, pallid, ranging in length from minute to extremely long; prodorsal setae of Abd IV–VIII progressively more hook-like, that of Abd VII conspicuous, red-brown; ventral setae of Abd III–VII and Abd X strongly hooked and pigmented. Head pallid except for a parietal stripe, genae and ventral areas dusky. Labrum gently rounded. Mandibles dusky with darker tips. Pronotum dusky. Abd II–VII with major *dpls* and *vpls* approximately 10× longer than the minor seta. Abd VIII with *dpls* subequal in length, elongate, 3× longer than other major *dpls*. Abd IX with 1 dorsal, 2 pleural setae extremely elongate, strongly curved. Anal hooks (Abd X) with conspicuous basal extensions.

Material examined.—TRINIDAD: Curepe, Oct. 1983 (F. D. Bennett). 6 larvae ex laboratory stock on *Salvinia molesta*, Brisbane, Sept. 1984 (D. P. A. Sands).

### *Cyrtobagous salviniae* Calder and Sands
Figs. 2, 14–15

Cyrtobagous salviniae Calder and Sands 1985: 57–64.

Larva.—Maximum size 4.0 × 1.0 mm. Head width: 1st instar, 0.18 mm; 2nd instar, 0.22 mm; 3rd instar, 0.27 mm. Setal index as in Table 1. Fine setae pallid, generally less elongate than in *C. singularis*. Hooked setae pale brown; *prs* of Abd VII not outstanding. Head pallid only on frons and a small lateral parietal area, elsewhere dusky brown. Labrum truncate. Tormae contiguous at base. Mandibles reddish. Pronotum dusky brown. Abd II–VII with major *dpls* 3× longer than the minor seta; major *vpls* 2.5× longer than minor seta. Abd VIII with *dpls* unequal in length; major seta elongate, 3× length of minor seta. Abd IX with 1 dorsal, 2 pleural setae extremely elongate and curved as in *C. singularis*.

Material examined.—BRAZIL: Joinville, 1978 (I. W. Forno). 6 larvae ex laboratory stock on *Salvinia molesta*, Brisbane, Sept. 1984 (D. P. A. Sands).

BIOLOGY

Estimates were made of the abundance of *C. singularis* and of plant damage at a number of sites on the Zambezi River, Zimbabwe, between Kazungula and Lake Kariba, and for *C. salviniae* in Queensland (Qd) and Northern Territory (NT), Australia. Three samples of salvinia mat were collected from each locality with a scoop net (30 × 30 cm with 2 m handle) and transported in plastic bags for microscopic examination. Adults and larvae per m² were counted. The numbers of buds damaged and rhizomes tunnelled per m² were recorded. When larvae were located by examining terminal growth, their positions on or in the plant, and any damage distinguishable from adult feeding, were then recorded.
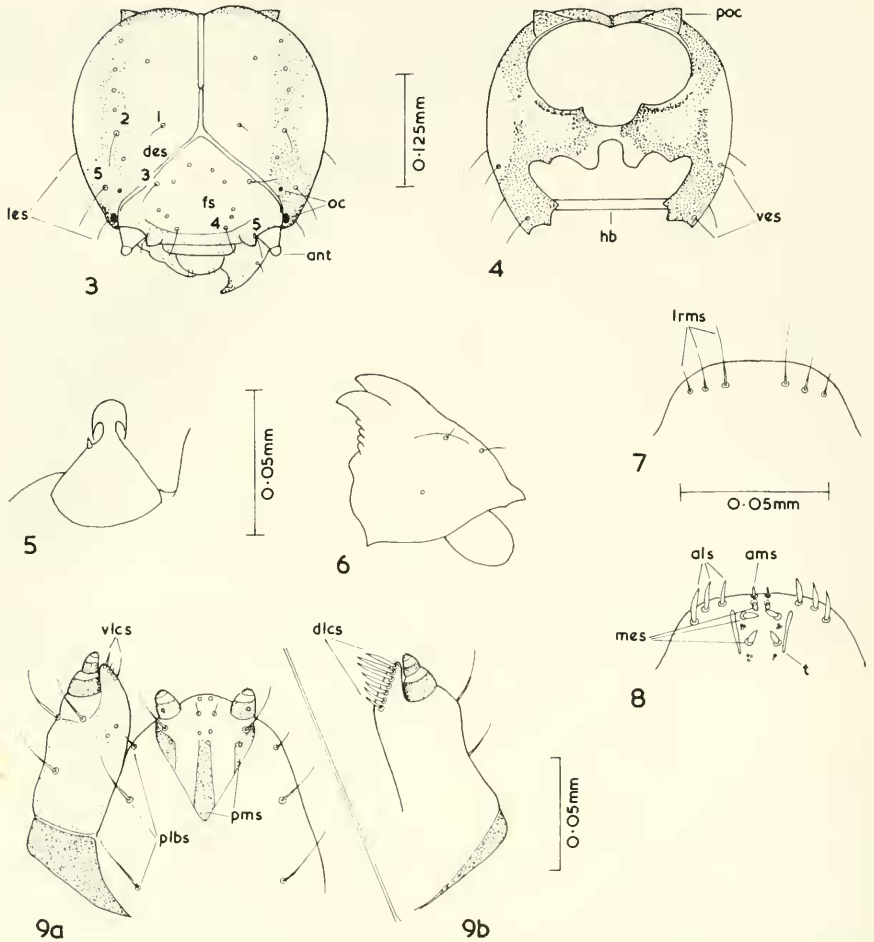
Figs. 3–9. *Cyrtobagous singularis* larva. 3, Head, dorsal view. 4, Head, ventral view. 5, Antenna. 6, Mandible. 7, Labrum. 8, Epipharyngeal lining. 9, Maxilla and labium (a, ventral view; b, maxilla, dorsal view).

In Australia, larvae of *C. salviniae* were all located tunnelling in the rhizomes of the host plant, salvinia, whereas in Zimbabwe, only one larva of *C. singularis* was found that had partly entered the petiole of a leaf. All others were found externally between the apical, unopened pair of leaves.

No significant difference was found between the numbers of buds and terminal leaves attacked by larvae of each species (*C. salviniae*: 1.67 [±0.23 SE, n = 30]; *C. singularis*: 1.35 [±0.15 SE, n = 17] per larva) but the type of damage differed for each species. Advanced larvae of *C. singularis* produced longitudinal "mines" in the expanding buds whereas first-instar *C. salviniae* destroyed young buds before the older larvae tunnelled into the rhizome. Quantitative differences in damage by the two species to rhizomes and root petioles were pronounced. There was no tunnelling in nodes, internodes or root petioles by *C. singularis* larvae, but each larva of *C. salviniae* tunnelled, 0.67 (±0.13 SE) nodes, 0.93 (±0.12 SE) internodes and 0.53 (±0.13 SE) root petioles. External scars were associated with 0.41 (±0.12
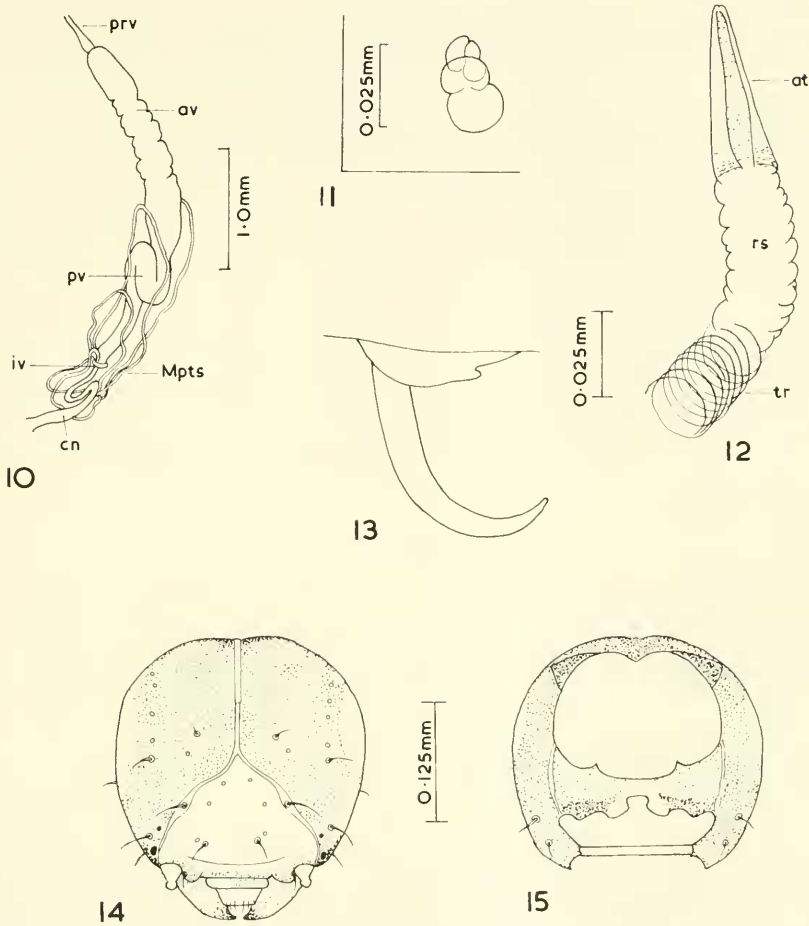
Figs. 10–15. *Cyrtobagous* larvae. 10–13, *C. singularis.* 10, Alimentary canal. 11, Thoracic spiracle, showing alignment. 12, Abd VII spiracle. 13, Anal hook. 14–15, *C. salviniae.* 14, Head, dorsal view. 15, Head, ventral view.

SE) of *C. singularis* larvae but none were associated with the internal-feeding larvae of *C. salviniae.*

The abundance of *C. singularis* in Zimbabwe differed considerably from that of *C. salviniae* in Australia (Table 2). Only at Msuna were adults of *C. singularis* abundant, with 24 adults per m^2. By contrast, at Wappa Dam, Queensland, 105 adults per m^2 of *C. salviniae* were recorded even before the salvinia mat had begun to collapse.

DISCUSSION

Differences in the biology of two *Neochetina* species were noted by DeLoach and Cordo (1976), but whereas these have not as yet been shown to relate to their potential as biological control agents of water hyacinth, the differences in feeding behavior of *Cyrtobagous* studied in the laboratory (Sands and Schotz, 1985) were clearly related to the different impact made by each species on salvinia. Under

Table 2. Population densities of *Cyrtobagous* and damage to salvinia in Zimbabwe and Australia.

Locality	Altitude (m)	Date	Water Temperature (°C)†	Nos./m²		% *S. molesta* Damaged*	
				Adults	Larvae	Buds	Rhizomes
C. singularis in Zimbabwe							
Kazungula (17°45′S, 25°20′E)	1060	11.x.84	27.0	3	9	<1	0
Victoria Falls (17°56′S, 25°50′E)	990	5.x.84	26.5	<1	<1	4	0
Msuna (18°01′S, 26°54′E)	630	13.x.84	31.5	24	<1	26	0
Lake Kariba (16°32′S, 28°52′E)	604	16.x.84	31.0	3	<1	5	0
C. salviniae in Australia							
Mt. Malloy, Qd (17°22′, 145°15′E)	335	16.iv.84	24.0	66	27	52	72
Kaban, Qd (17°33′, 145°24′E)	900	18.iv.84	22.0	27	21	34	3
Wappa Dam, Qd (26°35′S, 152°49′E)	44	22.i.85	26.5	105	69	90	18
Howard River, NT (12°29′S, 131°06′E)	20	22.vii.83	28.5	43	41	81	29

† At 2 cm depth.
* Buds damaged by adults and larvae, rhizomes tunnelled by larvae.

field conditions, observations on larvae of *C. singularis* in Zimbabwe and on *C. salviniae* in Australia confirm that they each feed on separate parts of the plant.

The larvae of the two *Cyrtobagous* are easily distinguished by their morphology. It is possible that the longer setae of *C. singularis* are an adaptation to external feeding, where they aid movement from one submerged part of the host to another, in contrast to the shorter setae of *C. salviniae* whose larvae tunnel internally within the rhizomes.

Until recently (Procter, 1984), the establishment of *C. singularis* on salvinia in the Chobe and Zambezi Rivers had not been comfirmed. During the present study, *C. singularis* was collected in small numbers at several localities visited between Ngoma, Botswana and Lake Kariba, Zimbabwe, but was not taken at Chirundu or Mana Pools, downstream from Lake Kariba. It is possible that this weevil had been overlooked on Lake Kariba following its establishment from the releases made in 1971 (Bennett, 1975) or on the Chobe and Linyanti Rivers from 1972–1974 (Edwards and Thomas, 1977). Several other factors appear to relate to a decrease in abundance of salvinia on Lake Kariba which may not be entirely due to insect damage (Marshall and Junor, 1981).

C. singularis was much less abundant at all places visited in southern Africa when compared with *C. salviniae* at certain localities in Australia. The maximum of 24 adult *C. singularis* per m² recorded at Msuna (Table 2) may have resulted from concentration of weevil numbers at a site where water had receded in a narrow lagoon entering the Zambezi River. No seasonal increase in numbers has

been observed in Botswana (D. Procter, pers. comm.). Much higher numbers of *C. salviniae* have been reported at several localities in Australia where biological control of salvinia has been achieved (Room et al., 1984).

Salvinia has remained a serious weed upstream in the eastern Caprivi Strip (Toerien et al., 1984) where *C. singularis* has not controlled the weed. Recently, *C. salviniae* was released at sites in the eastern Caprivi Strip (Schlettwein and Hamman, 1984). During the present study, adults of both species were recovered at Ngoma, Botswana, in October 1984, where the damage by *C. salviniae* appeared to be similar to that recorded in Australia. At Ngoma differences in feeding characteristics of the two species were observed within 300 m of each other.

It appears that both the nature of damage caused by feeding and their relative abundance on *S. molesta* show differences between the two *Cyrtobagous* and that these factors contribute to the success of *C. salviniae* as a biological control agent where *C. singularis* has failed. The spread of *C. salviniae* over areas where *C. singularis* has already established in southern Africa might be expected to result in effective control of salvinia.

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